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INITIATION OF EXPLOSIVES BY EXPLODING WIRES

IV. EFFECT OF WIRE LENGTH ON THE INITIATION OF PETN BY EXPLODING WIRES

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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IV. EFFECT OF WIRE LENGTH ON THE INITIATION OF PETN BY EXPLODING WIRES

Prepared by
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ABSTRACT: The effect of wire length on the initiation of PETN by exploding platinum wires was investigated using a one micro-farad capacitor charged to 2000 volts as the energy source. The energy density deposited in the wire was found to increase with decreasing wire length but there is an optimum length for effecting detonation. This is apparently governed by the energy density deposited in the wire and a minimum critical volume of explosive which must be initiated.

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WHITE OAK, MARYLAND

NOLTR 64-61 4 May 1964

INITIATION OF EXPLOSIVES BY EXPLODING WIRES
IV. EFFECT OF WIRE LENGTH ON THE INITIATION OF PETN BY EXPLODING WIRES

This report is Part IV of an investigation concerning the initiation of explosives by exploding wires. The work was performed under Task RUME-4E000/212-1/F008-08-11 Problem No. 019, Analysis of Explosive Initiation.

The results should be of interest to personnel engaged in initiation research and design of exploding bridgewire ordnance systems.

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Commander

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By direction

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INTRODUCTION

1. This is the fourth report describing experimental results obtained from a continuing investigation of the interaction between exploding wires and explosives. Previous investigations[1,2] had shown that circuit inductance and resistance should be kept to a practical minimum to best detonate PETN. It was also found that the wire diameter can be chosen so as to favor time reproducibility of explosion, general functioning reliability, or vigor of the wire output[3].

2. Earlier work with a 1-mil diameter platinum wire had shown that the wire length should be chosen so as to eliminate a definite current dwell. With the 1-mil diameter wire, the resurge (resumption of current flow) after a definite current dwell had no effect on whether or not detonation in PETN was produced. An extensive analysis was not made of the electrical characteristics during the early investigation because of the large amount of hash or noise on the current and voltage waveforms. Clearer waveforms were obtained with a 2-mil diameter platinum wire which was also found to be the optimum diameter for reliable initiation of PETN by the test circuit. The present phase of the investigation was made to examine in more detail the effects of wire length using a 2-mil diameter wire. Conditions that determine whether or not detonation develops in the explosive (PETN) were also studied.

ELECTRICAL CIRCUITRY

A typical exploding bridgewire circuit for ordnance purposes uses a one-microfarad capacitor charged to 2000 volts. The actual test circuit used for this investigation is shown in Figure 1. The transmission line was kept as short as possible consistent with the necessity for testing in an explosive firing chamber. The parameters for the test circuit were:

$$C = 0.97 \text{ microfarad}$$

$$L = 0.58 \text{ microhenry}$$

$$R = 0.35 \text{ ohm}$$

$$V_o = 2000 \text{ volts}$$

Methods used for the determination of the circuit parameters are given in references 1 and 2.

References are listed on page 8.

TEST PROCEDURE

A test series of shots was first run to determine the optimum wire length for effecting detonation in the PETN. Wire lengths ranging from 0.0125-inch to 0.200-inch were investigated. The optimum diameter platinum wire (2-mil) found best for reliable initiation of PETN was used for all the tests. Oscillograms were taken of the current and voltage waveforms concurrent with a smear camera picture for every test shot. The test fixture and experimental methods described in reference 1 were used. Instantaneous resistance, instantaneous power, and cumulative energy computations were made and compared for the various length wires.

Special tests were subsequently made to clarify the reasons for the existence of an optimum length. One test was made to investigate the possibility of thermal quenching from heat absorption by the brass pins to which the wire was soldered. Other tests were run to measure the plasma expansion when flush-mounted bare wires of various lengths were exploded.

EXPERIMENTAL RESULTS

Six different lengths of 2-mil diameter platinum wire ranging from 0.0125- to 0.200-inch were tested for their ability to effect detonation in PETN. A test series was run in which the density of the PETN was gradually increased. Increasing the density of PETN lowers the probability of effecting detonation. The test results are shown in Table 1. There is an optimum wire length of approximately 0.050-inch for effecting detonation in PETN by the 2-mil diameter platinum wire under circuit conditions employed. Two-mil platinum wires up to 0.100-inch length can cause detonation in PETN at a density of 1.0 g/cm^3. As the density of the PETN is increased above 1.0 g/cm^3, both the shorter and longer lengths of the test wires gradually fail to effect detonation.

A different type of growth to detonation was observed in three test shots during the series. It was observed in these three shots that reaction commenced at the time of wire burst and detonation developed, approximately 1-microsecond after wire burst on only one side of the wire. This resulted in an unsymmetrical growth to detonation of the PETN. See Figure 2. The greater pressure on the side where detonation developed appeared to push the wire plasma to the opposite side where detonation commenced approximately 2-microseconds after burst This type of growth to detonation occurred at densities where the possibility of effecting detonation was marginal. The same unsymmetrical growth to detonation was observed during the

diameter studies[3] at densities where the possibility of effecting detonation was marginal. At that time the unsymmetrical growth was thought possibly to be a happenstance from uneven loading of the PETN.

Previously it was observed[2] using 1-mil diameter platinum wires with lengths ranging from 0.025- to 0.400-inch that the probability of effecting detonation was directly related to the current density. Data obtained with the shorter 2-mil diameter wires did not verify this contention. Figure 3 shows that the 0.0125-inch length wire had the highest current density at burst. Yet it was not the most effective wire length for producing detonation in PETN. Therefore, the ability to effect detonation can only be related to the current density for very specific conditions. The shorter the wire, the more contiguous the resurge is with the initial current pulse. The 0.200-inch length gives a definite current dwell.

Examination of the voltage waveforms of the various length platinum wires shows that for the experimental range investigated the longer the wire, the more definite the so-called vaporization plateau and the higher the peak voltage. See Figure 4. The highest peak voltage observed was almost double that of the original capacitor voltage.

Examination of the resistance curves shows the expected increase in resistance with increasing wire length. See Figure 5. The longer the wire, the more constant the resistance during the so-called vaporization plateau. The 0.200-inch length wire shows an extremely sharp rise in resistance indicating the start of a definite current dwell. Wire lengths of 0.025- and 0.050-inch, which were the best lengths for effecting detonation in PETN, reached peak resistances of 1.5 and 2.8 ohms respectively.

Examination of the power inputs to the various length wires shows the 0.075-inch length wire to have the highest peak power. See Figure 6. Peak power occurs at approximately 0.6 microsecond at the time the current just starts to dip and the resistance is rapidly increasing. A comparison of the power input on a per unit length (or per unit volume) basis shows that the rate of energy deposition increases with decreasing length. See Figure 7.

Examination of Figure 8 shows that the longer wires because of their higher initial resistances initially absorb energy at a greater rate than the shorter wires. Energy deposition into the 0.200-inch length wire effectively stopped with the onset of a definite current dwell. The 0.075-inch length wire appears to be the optimum length for the largest energy transfer from the capacitor to the wire for the circuit conditions used. It has

the highest peak power and absorbs the most energy. However, it is not the optimum length for effecting detonation in PETN. If the energy inputs to the various length wires are compared to the amount of energy necessary to vaporize the wire, it is found that wires less than approximately 0.060-inch long receive more energy than necessary for complete vaporization at time of burst. See Figure 9. Energy profiles for the various length wires are shown for selected times during the interval of importance. It was also observed with the 0.100-inch length wire that the wire does not have to be completely vaporized at burst to effect detonation. However, as the PETN loading density is increased, the 0.100-inch length wire is the first to fail to effect detonation.

Examination of the energy density in the wires shows that the energy density increases with decreasing length (assuming all energy is deposited in wire). See Figure 10.

Since the electrical characteristics of the shorter wires indicated that small lengths should be effective, possible reasons for the failure of the shorter lengths to effect detonation in PETN were investigated. Quenching because of heat absorption by the brass leads to which the bridgewire was soldered was first investigated. Brass has a thermal conductivity roughly 3 orders of magnitude higher than the plastic plate holding the brass pins (0.26 cal/cm sec °C vs 0.35×10^{-3} cal/cm sec °C). Two series of ten shots were run with the diameter of the brass pins decreased from 0.052- to 0.030-inch, reducing the metal surface in contact with the explosive by approximately 65%. No improvement in effecting detonation of PETN was observed when compared to shots with the larger brass pin. Both series were run with bridgewire lengths of 0.0125- and 0.025-inch and with the PETN at a density of 1.15 g/cm^3. The possibility of insufficient energy deposition into the shorter wires was also considered. Wires less than 0.075-inch long absorb decreasing amounts of energy. See Figures 8 and 9. However, on a unit length or volume basis, both the peak power and energy density increased as the wire length decreased. A more efficient energy transfer on a unit length basis would then be expected as the bridgewires become shorter. The possibility of not igniting a sufficient volume of PETN was also considered. It is well known that a minimum critical volume of explosive must be initiated for propagation to continue after initiation. Examination of the vigor of the plasma expansion into air at the mid-point of each wire revealed that an almost equal quantity of explosive would be contacted radially for each wire length. See Figure 11a. Since camera observation was at the mid-point of the wire, greater lateral expansion would be expected from the shorter wires. When lateral expansion is prevented, the radial expansion is more vigorous for the shorter wires which have the higher energy

densities. See Figure 11b. Comparison of the volume of plasma expansion using lateral confinement shows that as one proceeds from the shorter wires to the longer ones the volume of explosive that would be contacted would increase rapdily up to the 0.050-inch length and then at a slower rate for the longer wires. See Figure 12.

DISCUSSION

The growth of explosion is a critical process. For any explosive there is some minimum quantity which must be initiated for propagation to continue. Chemical reaction, once initiated on the surface of the explosive, progresses inwards at a rate determined by the temperature and pressure. Therefore, the temperature and pressure in this critical volume must be sufficiently high to insure a rapid decomposition of the explosive. If energy is released rapidly enough, the initial reaction will undergo a transition to a self-sustaining detonation wave.

Initiation of an explosive by an exploding wire is caused by energy of electrical origin. The wire acts as a transducer between the stored energy in the capacitor and the explosive, transferring to the explosive heat, electromagnetic, and hydrodynamic energy. For the circuit values employed, it is believed that kinetic energy and heat transfer from the plasma play a more important role than the electromagnetic or shock energy. The hot plasma from the exploding wire envelops the explosive crystals adjacent to the wire, heating them and starting burning over a number of the crystal surfaces. The explosion of the wire must be vigorous enough to insure that a minimum critical volume is initiated. It is believed that one reason a hot intact wire cannot normally effect detonation of PETN is that only a limited quantity of explosive in contact with the wire is slowly decomposed.

Once the explosive is ignited; thermal factors will determine whether or not growth of explosion occurs. Energy contributions must be greater than energy losses to the surroundings. During this critical period there can be simultaneous electrical and chemical energy contributions. It was previously observed[3] during the wire diameter studies that the wire which exploded the most vigorously was not the best for effecting detonation because of a rapid drop in the electrical energy contribution immediately after wire burst. Wires giving a less vigorous explosion were found to be better because of the sustained electrical energy input. The chemical energy evolved is proportional to the volume of reacting explosive, while the heat lost is proportional to the surface area. The smaller the volume of explosive ignited, the greater the surface area to volume ratio. It is therefore favorable to make the wire

explosion as vigorous as possible (for the circuit parameters used) and to sustain the input of electrical energy during this critical period.

Lewis and von Elbe[4] have found that electrodes absorb some of the spark energy in the ignition of gases by sparks. This caused a sharp increase in the minimum ignition energy when the electrodes approached a critical distance. The electrode material did not affect the quenching distance because the heat conductivities of the solid electrodes were so much greater than those of the gases. The exploding bridgewire results showed no improvement in effecting detonation when the area of brass pin in contact with the PETN was decreased. Supporting the experimental results are the observations that confinement in the vicinity of an exploding wire or spark lowers the ignition energy for solid explosives. If the surrounding material acted mainly as a heat sink, an increase in the ignition energy would be expected instead of the observed decrease. Thermal quenching by the electrodes, which is quite important in gas ignition, appears to be of little importance in the initiation of solid explosives. Although it was observed that less total energy is absorbed as the wire length is decreased below 0.075 inch, the power and energy density per unit length increase with decreasing length. The existence of an optimum length for effecting detonation appears to be the result of the effect of the energy density deposited in the wire (the higher the energy density, the higher the temperature and pressure) and the necessity for igniting a sufficient volume of explosive. Figures 11b and 12 indicate that though the radial expansion of the wire plasma increased with increased energy density, the volume of explosive enveloped by the longer wires was likely to be greater. As the wire length increased above 0.075-inch, the total energy deposited decreases and there is less chance of creating the necessary pressure and temperature conditions for detonation to ensue.

It is interesting to note that the wire length which gives the best energy transfer from the capacitor to the wire during the interval of interest is not the best for effecting detonation in PETN for the parameters employed. This is another indication that the energy density is an important factor.

With the type of test run to determine the optimum wire length for effecting detonation in PETN, it is quite possible that the necessary minimum critical volume increases with the loading density. The tests would then indicate a longer wire length than necessary at lower loading densities. Since the density of the PETN in a practical item may increase under hi-G forces, the optimum length indicated by gradually increasing the loading density might be preferable.

CONCLUSIONS

1. With a fixed diameter and fixed firing circuitry there is an optimum length wire for effecting detonation in PETN. This optimum is apparently governed by the energy density in the wire and a minimum critical volume of explosive which must be initiated.

2. The energy density deposited in the wire increases with decreasing length.

3. The optimum length for effecting detonation does not necessarily correspond to the wire length which gives the best energy transfer from the capacitor.

4. A wire does not have to be completely vaporized at burst to effect detonation in PETN.

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1. Leopold, H. "Initiation of Explosives by Exploding Wires. I. Effect of Circuit Inductance on the Initiation of PETN by Exploding Wires" NOLTR 63-159 May 1963.

2. Leopold, H. "Initiation of Explosives by Exploding Wires. II. Effect of Circuit Resistance on the Initiation of PETN by Exploding Wires" NOLTR 63-244. May 1963

3. Leopold, H. "Initiation of Explosives by Exploding Wires. III. Effect of Wire Diameter on the Initiation of PETN by Exploding Wires", NOLTR 64-2.

4. Lewis, B. and von Elbe, G. "Combustion, Flames and Explosions of Gases" Academic Press Inc. New York 1951.

Table 1. Effect of Bridgewire Length on Detonation of PETN at Various Loading Densities

Bridgewire Length (inch)	Density of PETN (g/cm^3)									
	1.0		1.1		1.125		1.15		1.175	
	D	L	D	L	D	L	D	L	D	L
0.0125	2	0	2	0	1*	4	0	5		
0.025	2	0	2	0	3	2	3**	2	0	2
0.050	2	0	2	0	5	0	3	2	0	2
0.075	2	0	2	0	4	1	0	5		
0.100	2	0	0	2						
0.200	0	2								

* Unsymmetrical growth to detonation

** Two unsymmetrical growths to detonation

D = Detonation

L = Low Order

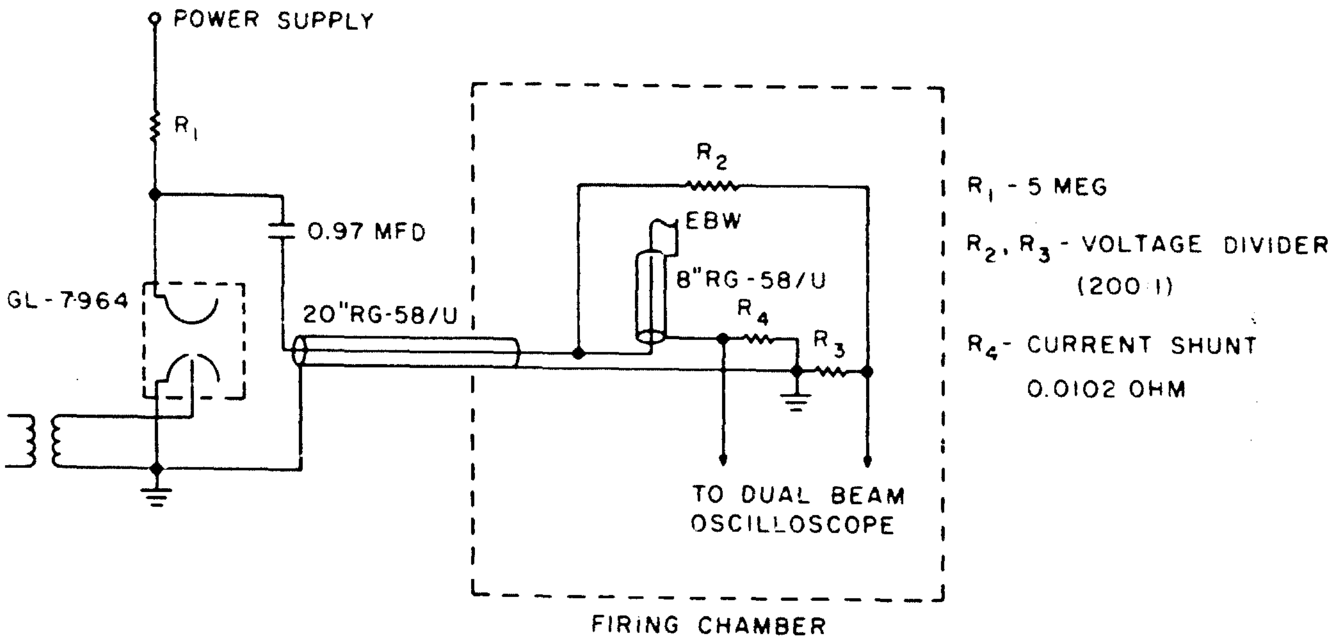

FIG. 1 FIRING CIRCUIT

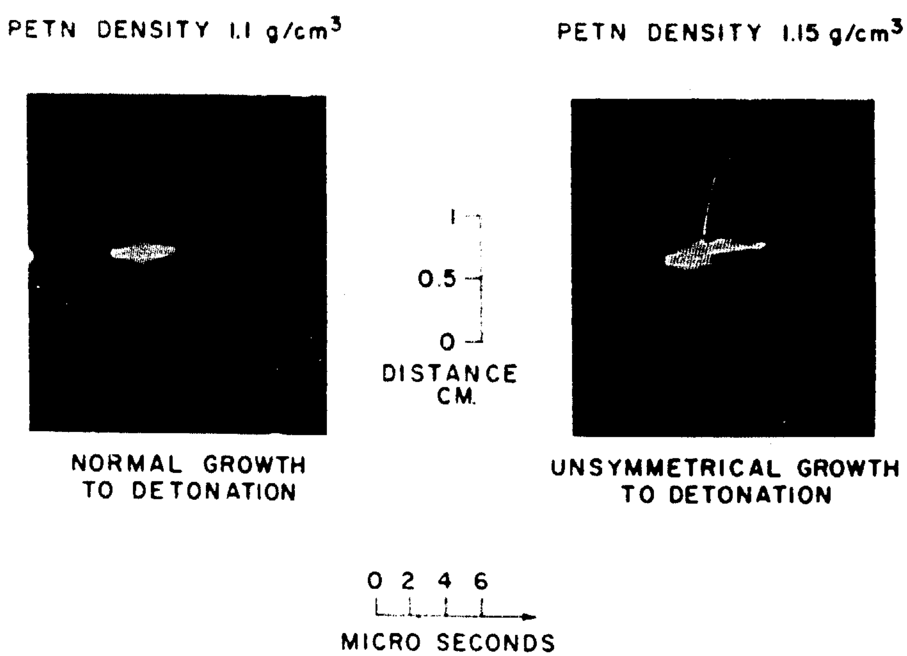

FIG. 2 COMPARISON OF NORMAL AND UNSYMMETRICAL GROWTH TO DETONATION

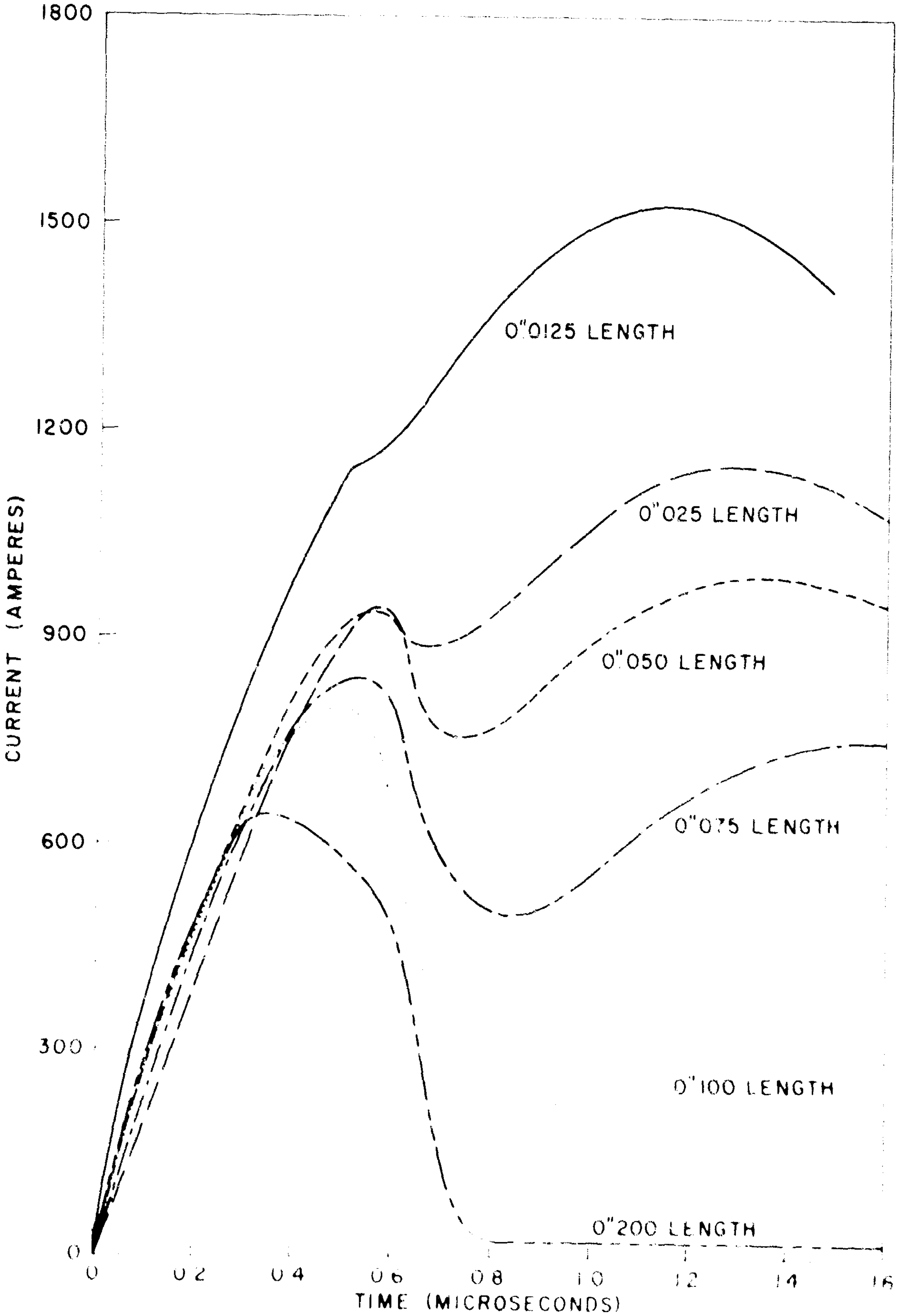

FIG 3 EFFECT OF WIRE LENGTH ON CURRENT PULSE

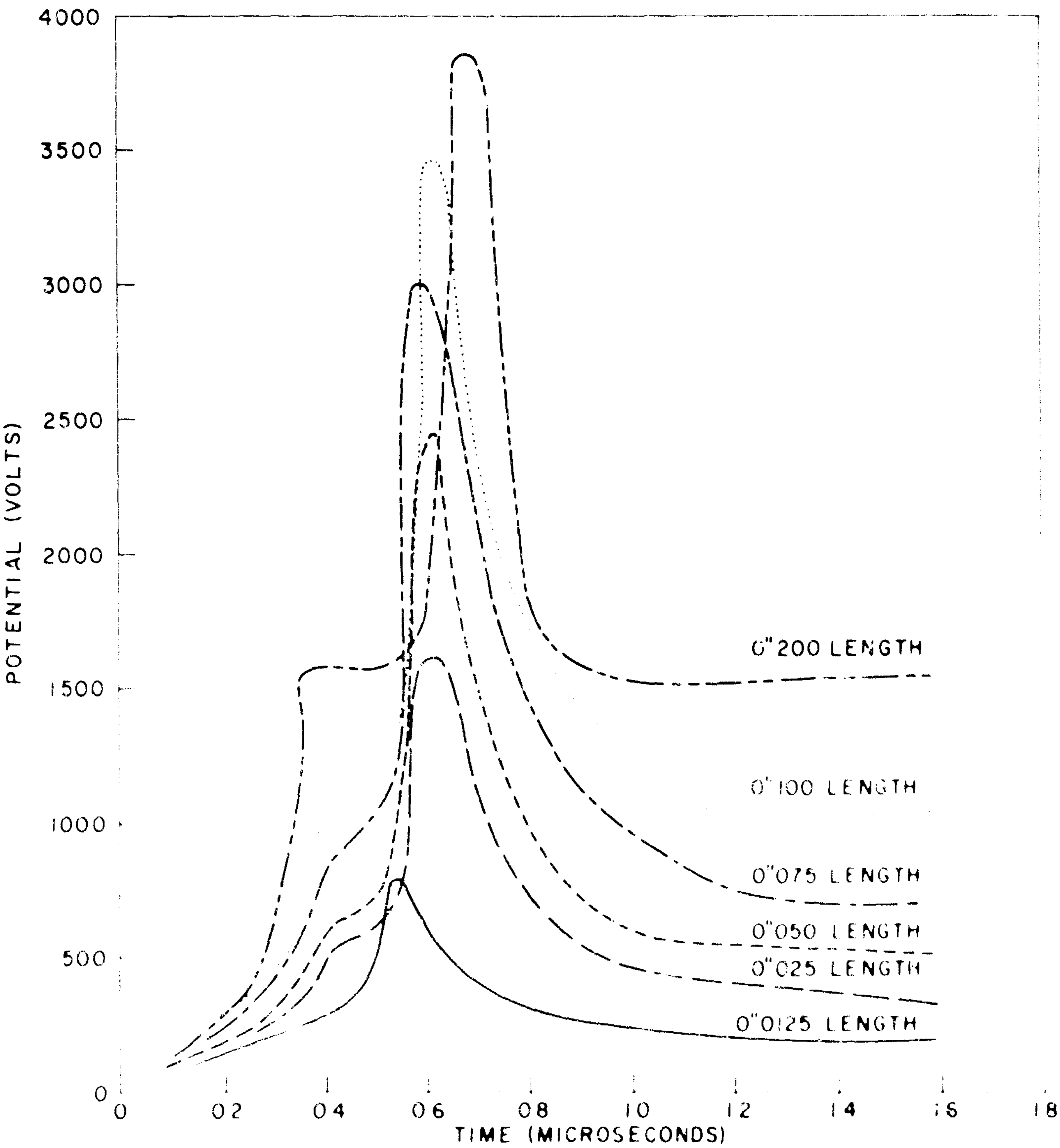

FIG 4 VOLTAGE ACROSS VARIOUS LENGTH WIRES

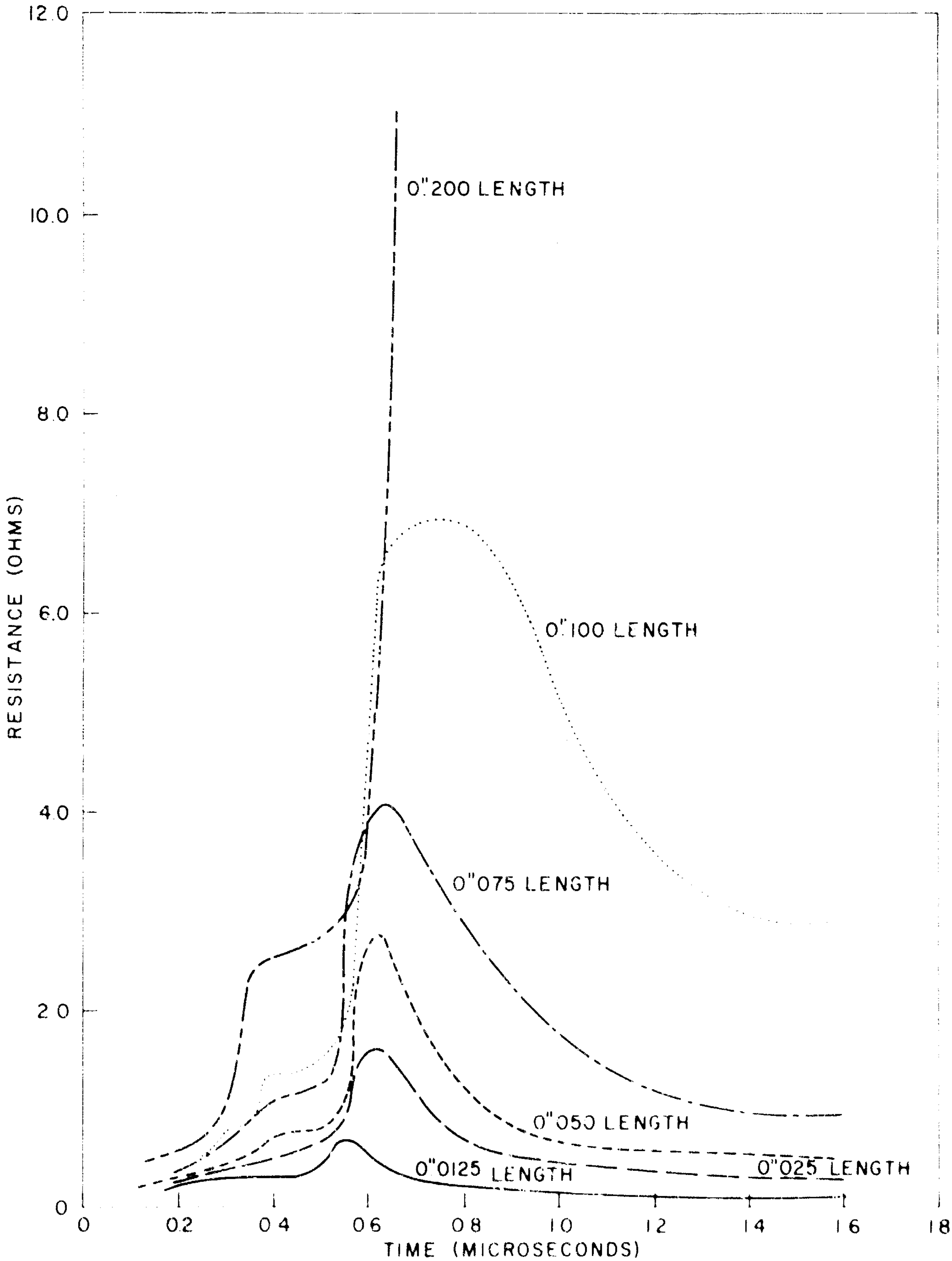

FIG 5 RESISTANCE OF VARIOUS LENGTH WIRES AT VARIOUS TIMES DURING EXPLOSION

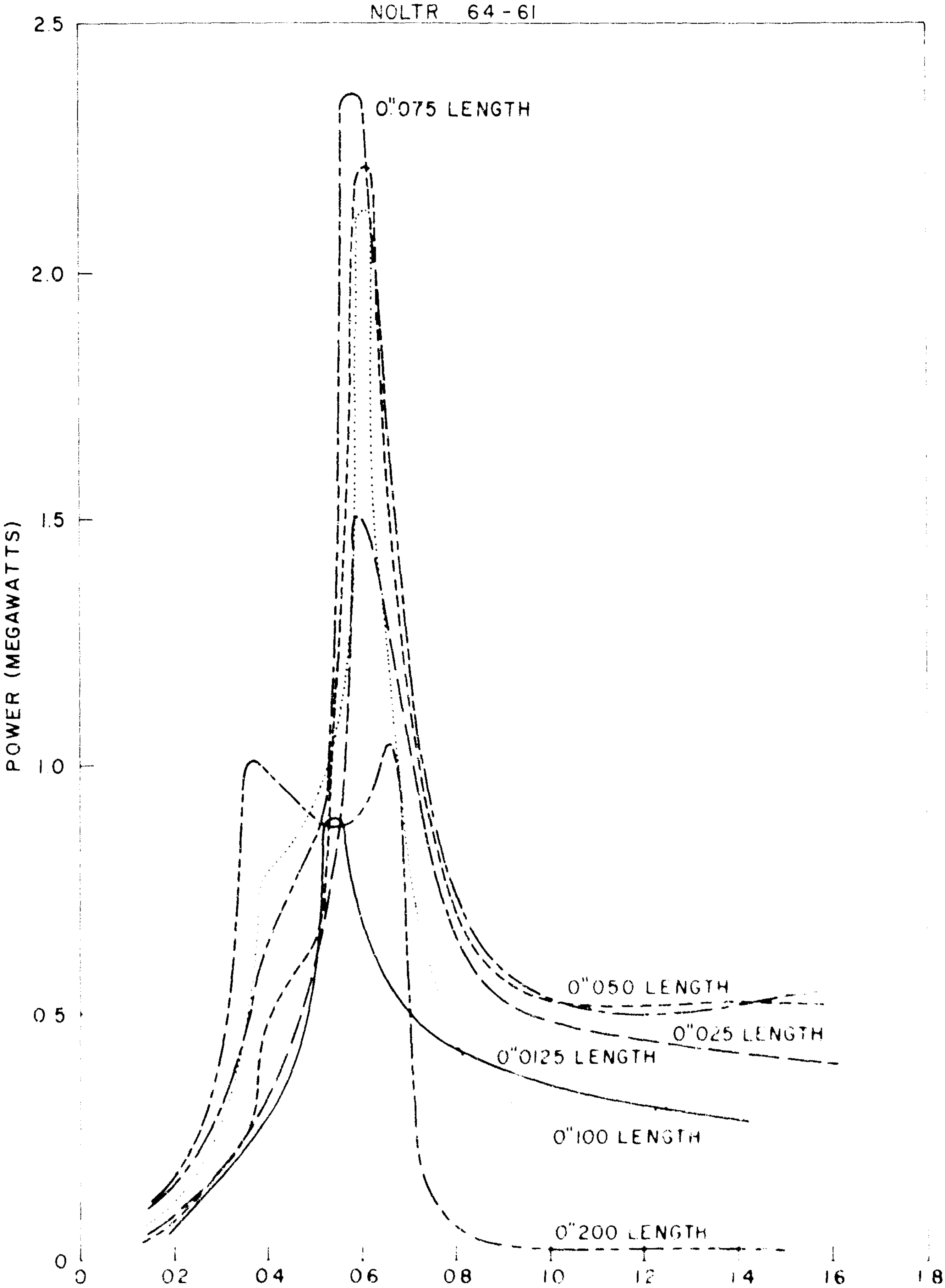

FIG 6 POWER INTO VARIOUS LENGTH WIRES

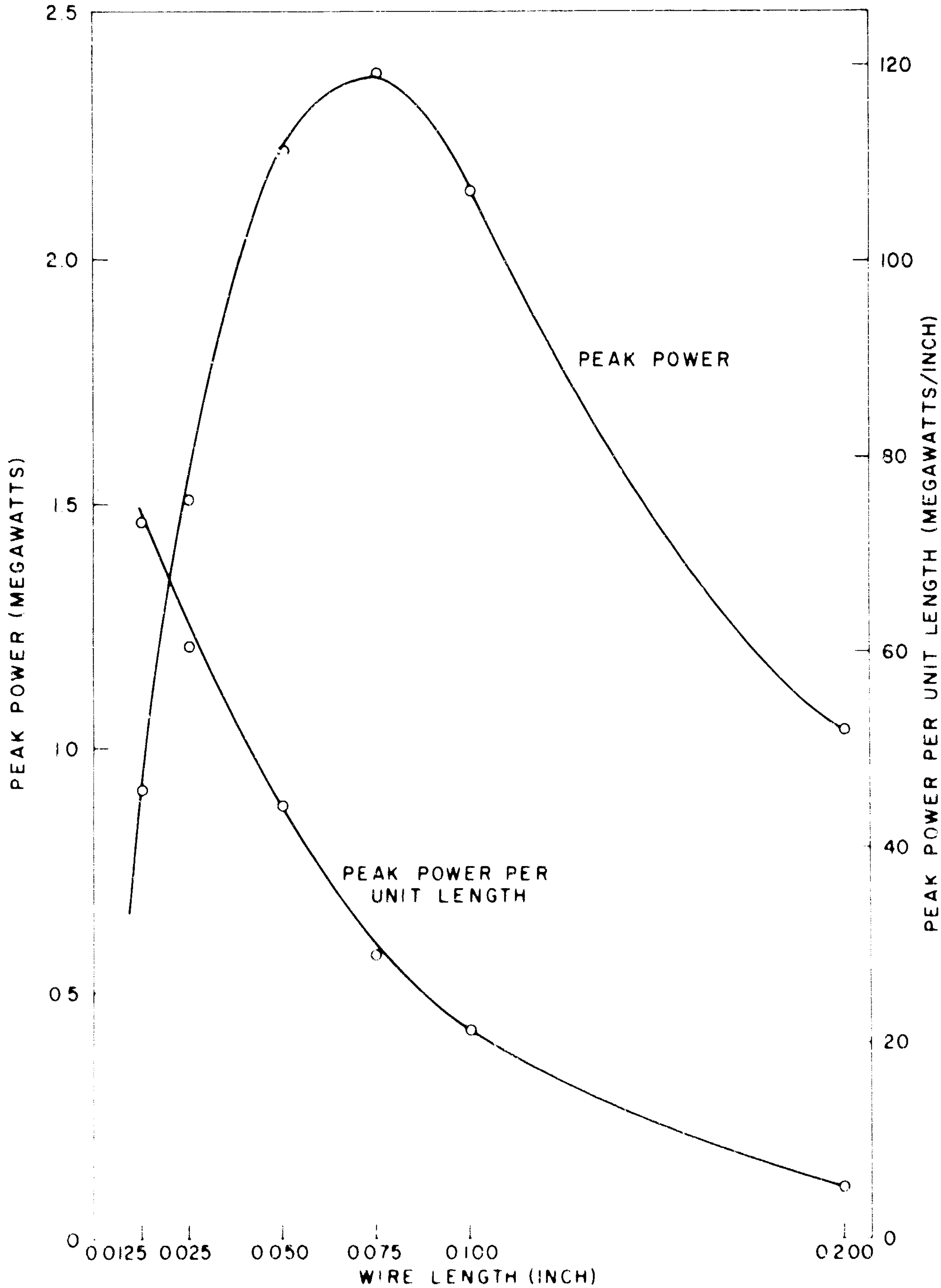

FIG. 7 PEAK POWER AS A FUNCTION OF WIRE LENGTH

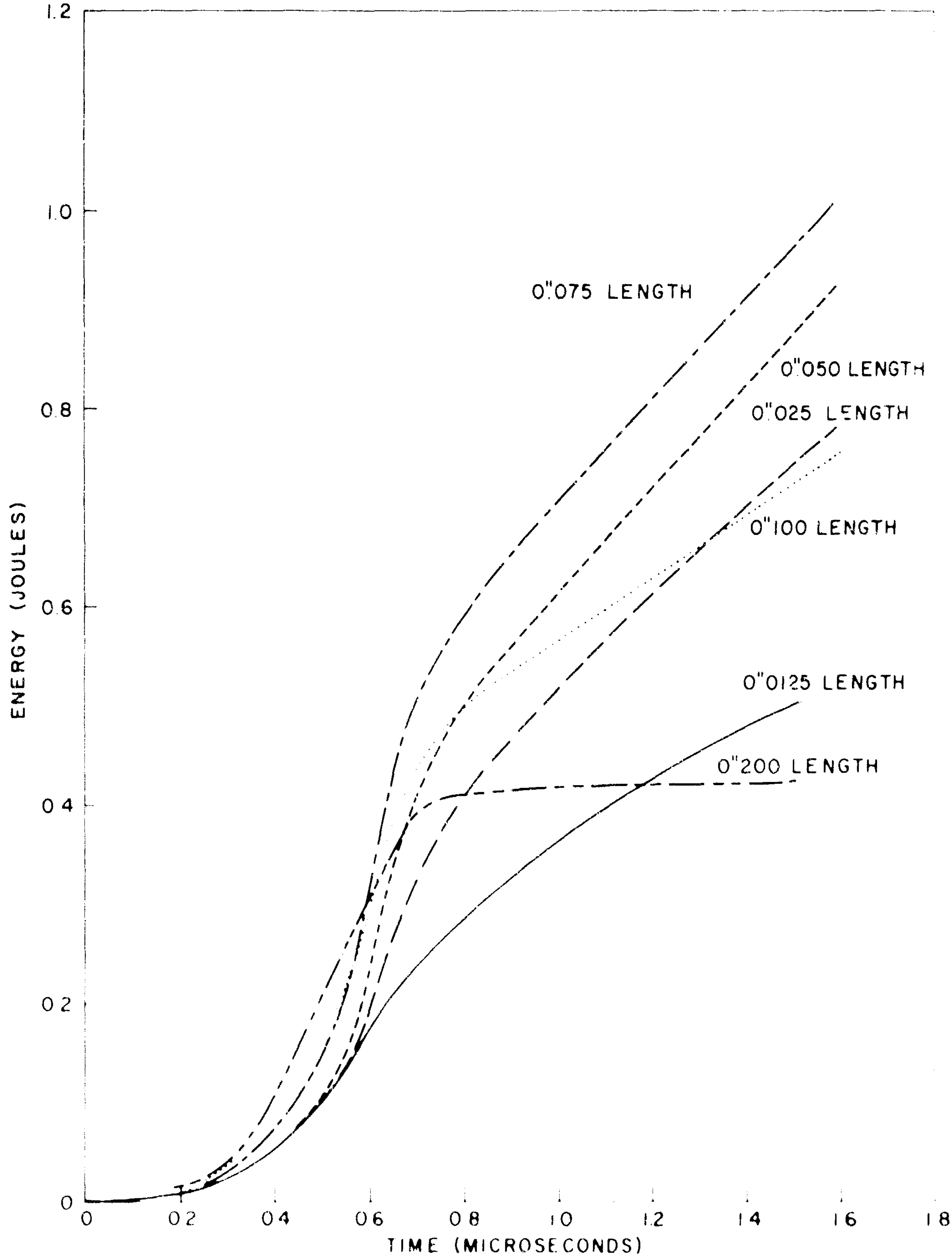

FIG 8 ENERGY DEPOSITION INTO VARIOUS LENGTH WIRES

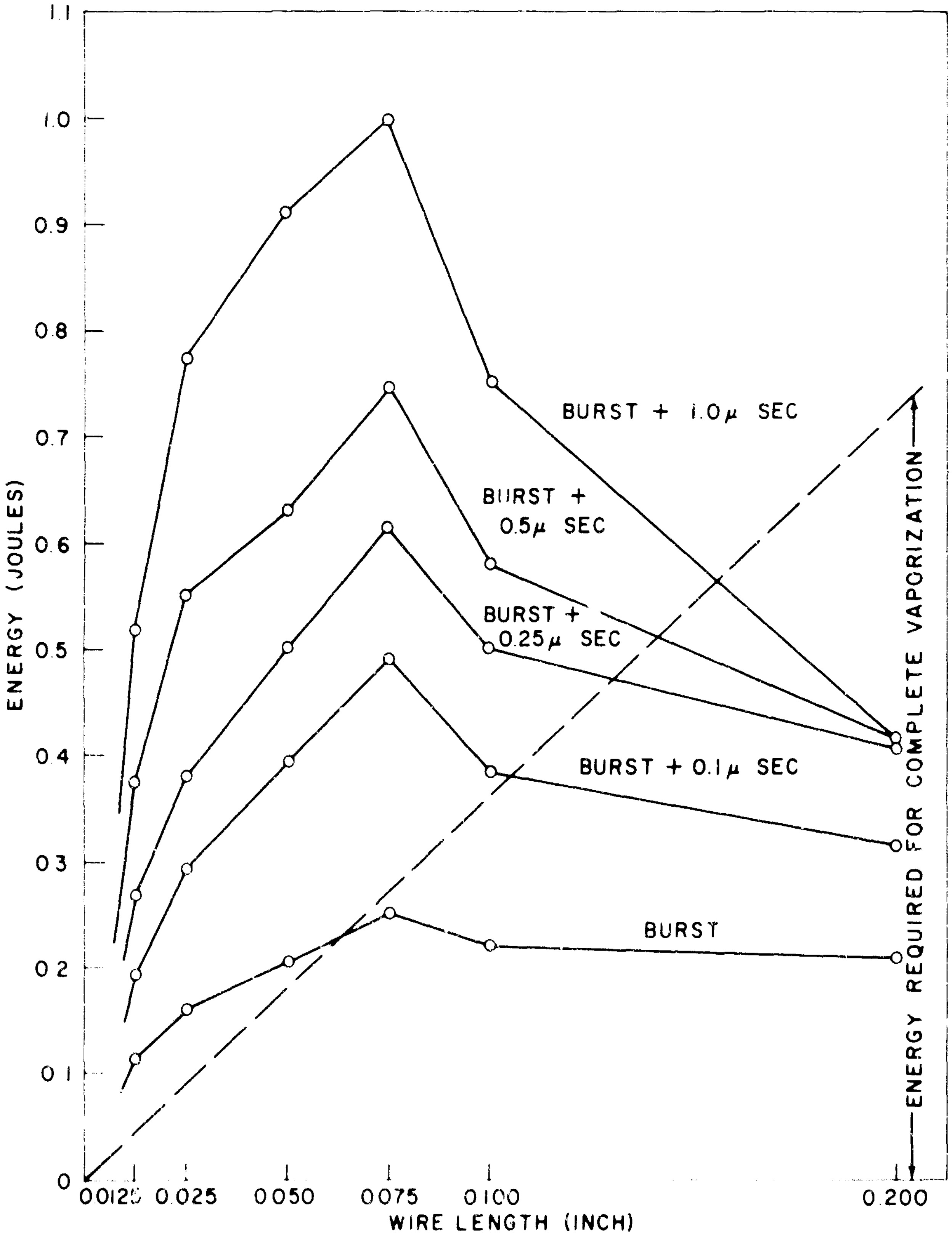

FIG 9 ENERGY DEPOSITION PROFILES FOR VARIOUS LENGTH WIRES

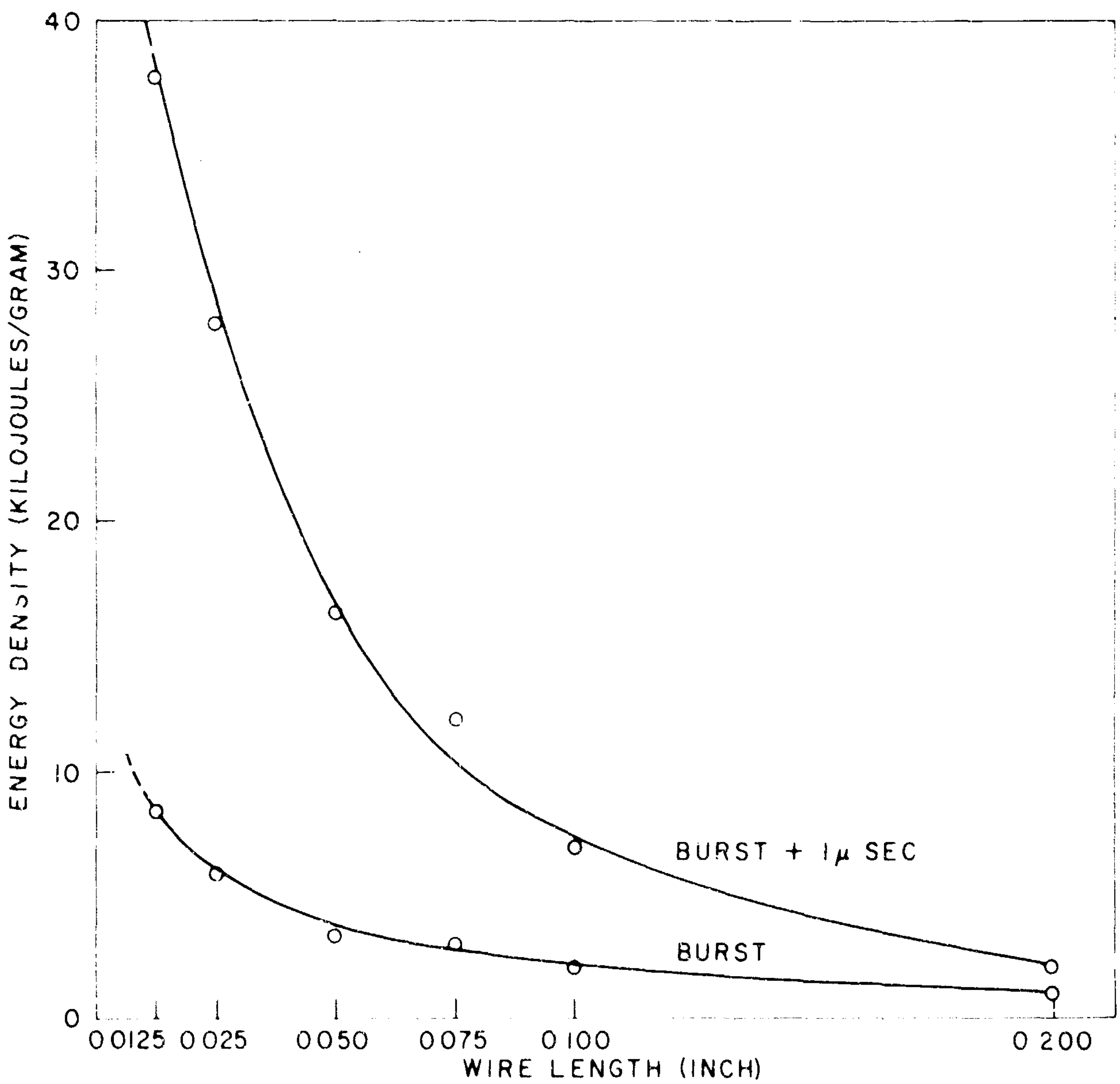

FIG 10 ENERGY DENSITY FOR VARIOUS LENGTH WIRES

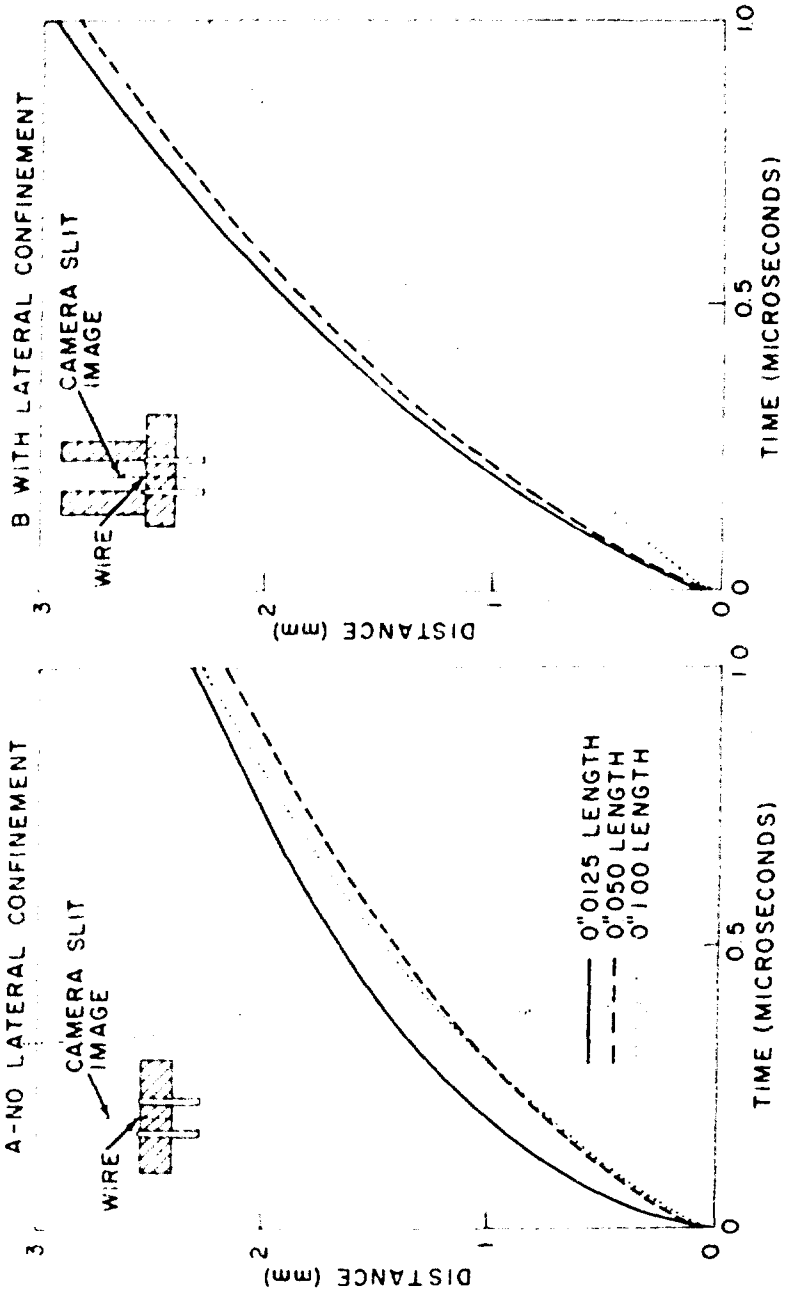

FIG. 11 EXPANSION OF PLASMA INTO AIR

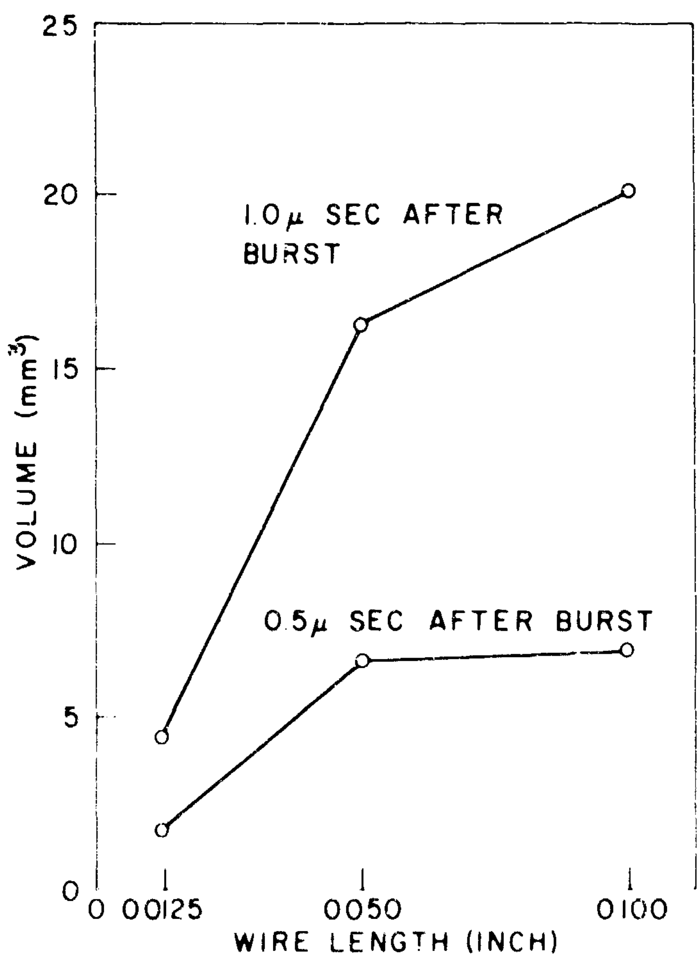

FIG 12 PLASMA VOLUME EXPANSION IN AIR FOR LATERALLY CONFINED WIRES